(54) **Title:** METHOD AND APPARATUS FOR USING TRELLIS CODED MODULATION SCHEMES FOR ENCODING AND DECODING TURBO PRODUCT CODES

(57) **Abstract:** An apparatus and method for encoding a block of data for a given codeword is disclosed. The block of data (210) is split (202) into a first stream (216) of u bits and a second stream (212) of k bits; and the second steam of k bits is encoded using a turbo product code encoding encoding scheme (204), to produce a stream (214) of n encoded bits. Pre-mapped coded symbols and pre-mapped uncoded symbols (218) are generated (206) from at least one of the plurality of n encoded bits and at least one of the plurality of the u bits in the first stream. A mapping (208) to a constellation symbol (220) having an I coordinate and a Q coordinate is then performed from the pre-mapped coded symbol and the pre-mapped uncoded symbol.

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

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METHOD AND APPARATUS FOR USING TRELLIS CODED MODULATION SCHEMES FOR ENCODING AND DECODING TURBO PRODUCT CODES

Related Applications

5   This Patent Application claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. Provisional Patent Application, Serial No. 60/302,819 filed July 3, 2001, and entitled "METHOD AND APPLICATION OF TURBO PRODUCT CODES FOR USE IN ADVANCED ERROR CODING AND MODULATION SYSTEMS FOR THE PROTECTION OF DATA IN COMMUNICATIONS". The Provisional Patent

10   Application, Serial No. 60/302,819 filed July 3, 2001, and entitled "METHOD AND APPLICATION OF TURBO PRODUCT CODES FOR USE IN ADVANCED ERROR CODING AND MODULATION SYSTEMS FOR THE PROTECTION OF DATA IN COMMUNICATIONS" is also hereby incorporated by reference.

Field of the Invention

15   The present invention relates to an apparatus and method thereof for the processing of turbo product codes, in general, and in particular, and an apparatus and method for using trellis coded modulation schemes and pragmatic trellis coded modulation schemes for encoding and decoding turbo product codes.

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Background of the Invention

The following primarily concerns itself with the use of Turbo Product Codes (TPC) in schemes that exhibit trellis coded modulation type schemes and further pragmatic trellis coded modulation type schemes.

25   Pragmatic Trellis Coded Modulation (PTCM) was first thought to provide a useful and general means of using a rate ½ convolutional code in a general system to provide for higher throughputs. In using the PTCM method in existing systems, certain bits that are passed through the system as uncoded bits use the power of convolutional codes as well as the Viterbi decoder to counteract the performance

30   degradation of these uncoded bits. The idea of using a single rate ½ convolutional encoder was also to develop excellent chips that can then be used in more general situations.

Figure 1A illustrates a general block diagram of an encoding system using the known PTCM method in relation to convolutional codes. Figure 1A illustrates a

35   demultiplexer 102 coupled with a ½ rate convolutional encoder 104 and a bit mapping module 106. In addition, Figure 1A illustrates the ½ rate convolutional encoder 104 being coupled with the bit mapping module 106. The known PTCM method utilizes input data 108 entering the system 100, wherein the demultiplexer 108 splits the input data 108 into two stream of bits. One stream of data is for the to-be encoded bits 112

that are sent to the rate ½ convolutional encoder 104, whereas the other stream is for the non-encoded or unencoded bits 110 that are sent directly to the bit mapping module 106.

Specifically, input data 108 arrives in a serial fashion into the demultiplexer 102, whereby the input data 108 is demultiplexed into the to-be encoded stream 112
5   and the non-encoded stream 110. The input data is received within the system 100 one bit at a time. Thus, the system 100 is able to take one bit of input data at a time and demultiplex the bit into the to-be encoded 112 and non-encoded streams 110. The to-be encoded stream 112 is sent into the ½ rate convolutional encoder 104, whereby the encoder 104 encodes the to-be encoded bit 112 and outputs an encoded X and Y
10   bit in their respective streams 114A and 114B to the bit mapping module 106. The X and Y bits are utilized as coded mapping symbols C_1 and C_2, in which the C_1 and C_2 mapping symbols are used by the bit mapping module 106 to form the constellation symbols (I,Q) 116. As stated above, the non-encoded bit stream 110 is sent directly to the bit mapping module 106. The non-encoded bit is utilized as an uncoded mapping
15   symbol U_1, in which the U_1 mapping symbol is used by the bit mapping module 106 in conjunction with the C_1 and C_2 mapping symbols to form the constellation symbols (I,Q) 116. The bit mapping module 106 receives the non-encoded symbol 110 as U_1 and also receives the X and Y bits 114A, 114B as coded symbols C_1 and C_2, respectively. The bit mapping module 106 uses the U_1, C_1 and C_2 symbols to form a
20   constellation symbol (I,Q) 116, in which the constellation symbol (I,Q) 116 is sent over the transmission channel to the receiving end 118 (Figure 1B).

Figure 1B illustrates a general block diagram of a decoding system using the known PTCM method in relation to convolutional codes. Figure 1B illustrates a soft decision metric generator (SDMG) 120, an uncoded bit decision generator (UBDG)
25   block 124, a rate ½ Viterbi decoder 122, a rate ½ convolutional encoder 126 and an output multiplexer 128. Once the symbol (I,Q) 116 is received at the receiving end 118, the symbol is sent to the SDMG block 120 as well as the UBDG block 124. The symbol 116 that is received in the SDMG block 120 is estimated into a metric of coded bits 132, whereby the metric of coded bits 132 are sent to the rate ½ Viterbi
30   decoder 122. The viterbi decoder 122 decodes the metric of coded bits 132 by generating hard decision estimates of the coded bits. The viterbi decoder 122 then sends the decoded bits 136 to the output multiplexer 128 in which the output multiplexer 128 waits to receive the unencoded bit 140 from the UBDG block 124.

After processing the coded bits 132, the viterbi decoder 122 also sends the
35   decoded bits 134 to a rate ½ convolutional encoder 126, whereby the convolutional encoder 126 reencodes the decoded bits into two new coded bits 138 and sends the two reencoded bits to the UBDG block 124. The UBDG block 124 receives the two reencoded bits 138 and uses these bits in conjunction with the (I,Q) symbol 130 received from the SDMG block 120 to de-map the unencoded bit. The UBDG 124

then sends the de-mapped unencoded bit 140 to the output multiplexer 128, whereby the decoded data is output 142.

Although the above system has been used with convolutional codes, the above system as well as the TCM and PTCM methods have not been used in conjunction with Turbo Product Codes. The TCM and PTCM methods have not been used with Turbo Product Codes due the very long block structure of TPCs. In addition, the TCM and PTCM methods have not been used with TPCs due to the difficulty of processing one symbol at a time for TPCs because of the block nature of the TPCs. This difficulty in processing one symbol at a time for a TPC block, compared to a convolutional code, causes a low code rate and low data throughput for the same number of bits per symbol.

What is needed is a system and method of encoding and decoding Turbo Product Codes using the PTCM method, thereby to achieving a higher code rate and data throughput without loss of performance in the system.

Summary of the Invention

In one aspect of the invention is a method of encoding a block of data for a given codeword. The method comprises receiving the block of data. The block of data is split into a first stream of u bits and a second stream of k bits. The second stream of k bits is encoded using a turbo product code encoding scheme, thereby producing a stream of n encoded bits. A pre-mapped coded symbol is generated from at least one of the plurality of n encoded bits. A pre-mapped uncoded symbol is generated from at least one of the u bits in the first stream. A constellation symbol having an I coordinate and a Q coordinate is mapped, wherein the constellation symbol is calculated using the pre-mapped coded symbol and the pre-mapped uncoded symbol.

Other features and advantages of the present invention will become apparent after reviewing the detailed description of the preferred embodiments set forth below.

Brief Description of the Drawings

Figure 1A illustrates a general block diagram of an encoding system using the known PTCM method in relation to convolutional codes.

Figure 1B illustrates a general block diagram of a decoding system using the known PTCM method in relation to convolutional codes.

Figure 2 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) encoding system in accordance with the present invention.

Figure 3 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) decoding system in accordance with the present invention.

Figure 4 illustrates a constellation map for an 8PSK modulation scheme in accordance with the present invention.

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Figure 5 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) encoding system 500 in accordance with the present invention for encoding a $(32,26)^2$ turbo product code.

Figure 6 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) decoding system in accordance with the present invention

5   for decoding a $(32,26)^2$ turbo product code.

Detailed Description of the Preferred Embodiment

Reference will now be made in detail to the preferred and alternative embodiments of the invention, examples of which are illustrated in the accompanying

10   drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following

15   detailed description of the present invention, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it should be noted that the present invention may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure aspects of the present

20   invention.

Figure 2 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) encoding system in accordance with the present invention. It should be noted that although the system in Figure 2 is described with respect to a trellis coding modulation scheme, the system in Figure 2 is useable in a pragmatic

25   trellis coding modulation scheme as well. As shown in Figure 2, the encoding system 200 includes a demultiplexing module 202, a turbo product code (TPC) encoder 204, a pre-mapping module 206 and a mapping module 208. The demultiplexing module 202 is coupled with the encoder 204 and the pre-mapping module 206. The TPC encoder 204 is coupled with the pre-mapping module 206. The pre-mapping module

30   is coupled with the mapping module 208.

In general, the demultiplexing module 202 receives input data 210 and multiplexes or splits the data 210 into two or more data streams. The turbo product code encoder 204 utilizes error correction schemes known in the art to encode the data that is to be encoded 212. The pre-mapping module 206 preferably interleaves more

35   than one data stream in such a way as to alleviate the problem of confidence levels being different for each of the bits in a given higher order modulation symbol. The bit mapping module 208 takes the coded bits provided by the pre-mapping module 206 and utilizes them to generate symbols having (I,Q) coordinates, in which the (I,Q) symbols are mapped in a constellation diagram. A constellation diagram for a 8PSK

diagram is shown in Figure 3. However, the present system may also be used in other sized constellations such as QPSK or any sized quadrature amplitude modulation schemes. It should be noted that although the above modules are only shown and described in Figure 2, other modules may be added or substituted to the encoding system 200 in accordance with the present invention.

5   As shown in Figure 2, input data 210 for a given codeword having a block size of k information bits preferably enters the system 200 in a serial fashion and is de-multiplexed by the demultiplexing module 202. The demultiplexing module 202 demultiplexes or splits the input data 210 into two streams, namely the non-encoded stream 216 and the to-be encoded stream 212. The number of bits from the input data
10   210 that are placed in the non encoded stream 216, designated as u bits, is preferably dependent on being one-half of the number of total encoded n bits that are output by the TPC encoder 204. Alternatively, the number of bits placed in the non encoded stream 216 is dependent on another ratio (i.e. two-thirds) of the total number of encoded n bits output by the TPC encoder 204.

15   The number of bits from the input data 210 that are placed in the to-be encoded stream 212 is preferably the number of k information bits that are input into the TPC encoder 204. However, it is understood that the demultiplexer 202 may be programmed to place any number of bits in the to-be encoded stream 212. The non encoded stream 216 and the to-be encoded stream 212 are preferably of unequal
20   length for a given codeword. Alternatively, the non encoded stream 216 and the to-be encoded stream 212 are of equal length for a given codeword.

       The non encoded bit stream 216 having u bits, is sent from the demultiplexer 202 directly to the pre-mapping module 206. In addition, the demultiplexer 202 sends the to-be encoded stream 212, having k bits, to the turbo product code (TPC) encoder
25   204. The TPC encoder 204 receives the k bits and encodes the k bits with a forward error correction scheme to generate n coded bits. Such forward error correction schemes include using extending hamming codes, parity codes and/or any other known turbo product code encoding scheme. In addition, the turbo product code encoder 204 may be of any known or available encoder. As stated above, the k bits
30   are encoded by the TPC encoder 204 to have n bits based on an (n,k) turbo product code encoding scheme. It should be understood that the present TCM encoding system 200 is not limited to any particular turbo product code.

       Considering that the encoding system 200 has a coding rate of k/n, where k is the number of data bits in the information block and n is the number of total bits in the
35   encoded block, the coding rate of a turbo product code encoded in a trellis coded modulation scheme is $(u+k)/(u+n)$. This is due to the presence of the uncoded u bits which are taken into account in the encoding and decoding processes. The uncoded u bits are designated as pre-mapped uncoded symbols U to map the coordinates (I,Q) for each symbol. For example, a constellation having 2^m points contains m bits per

constellation point, (I,Q), whereby the number of total m bits is equal to the sum of m_u uncoded bits and m_c coded bits. Therefore, mapping m_u uncoded bits and m_c coded bits to each constellation symbol (I,Q) in an 8PSK modulation scheme would have an $m=3$, $m_u=1$ and $m_c=2$. In other words, in an 8PSK modulation scheme, one uncoded U symbol and two coded C symbols are used to generate one constellation symbol.

5   Once the k bits have been encoded by the turbo product code encoder 204, the encoded n bits 214 are sent to the pre-mapping module 206. The pre-mapping module 206 is preferably set prior to designating the U_1, C_1 and C_2 pre-mapped symbols from the uncoded u bits and encoded n bits. The pre-mapping module 206 preferably designates two of the encoded n bits 214 in the stream as coded symbols C_1 and C_2.

10   Alternatively, the pre-mapping module 206 designates any predetermined number of encoded n bits 214 in the stream with a corresponding number of coded symbols. In addition, the uncoded u bits 216 are sent to the pre-mapping module 206, whereby the pre-mapping module 206 designates a predetermined number of u bits into a corresponding number of U uncoded symbols. In the preferred embodiment, the pre-

15   mapping module 206 designates one uncoded u bit as one uncoded U_1 symbol. The pre-mapped uncoded symbol U_1 as well as the pre-mapped coded symbols C_1 and C_2 are then sent to the mapping module 208. As stated above, the present invention is not limited to utilizing one pre-mapped uncoded U_1 symbol per two pre-mapped coded symbols C_1 and C_2 in generating a constellation symbol (I,Q). Thus, any

20   number of coded and uncoded symbols may be provided to the mapping module 208 by the pre-mapping module 206 in generating the constellation symbol (I,Q) for a given codeword.

The mapping module 208 receives the pre-mapped symbols U_1, C_1 and C_2 from the pre-mapping module 208. The mapping module 208 is preferably set prior to

25   modulating the U_1, C_1 and C_2 pre-mapped symbols into the constellation symbols (I,Q). The mapping module 208 is set to form the constellation symbols for any modulation scheme such as QPSK, 8PSK, 16 Quadrature Amplitude Modulation (QAM), 32 QAM, 64 QAM, 128 QAM, 256 QAM or any other quadrature modulation scheme. Once the mapping module 208 receives the group of pre-mapped

30   symbols, a look up table is preferably used to generate the (I,Q) symbols. Alternatively, the mapping is done using logic, modulation code or a ROM. The methods used to generate the (I,Q) symbols from the group of bits are generally well known in the art. As stated above, it is preferred that one pre-mapped uncoded symbol U_1 and two pre-mapped coded symbols C_1 and C_2 are used to form one

35   constellation symbol (I,Q). In addition, as stated above, it is preferred that the number of uncoded u bits sent from the demultiplexer 202 is ½ of the n bits encoded by the TPC encoder 204. Therefore, the mapping module 208 preferably outputs (n/2) (I,Q) symbols per codeword. As stated above, any number of uncoded u bits may be used in relation to any number of encoded n bits. Alternatively, the mapping module 208

outputs a different number of (I,Q) symbols per codeword. The (I,Q) constellation symbols are then transmitted over a transmission channel, whereby the symbols are received at the receiving end having a decoding system of the present invention. It is preferred that all constellation symbols are encoded for the given codeword before being sent over the transmission channel. Thus, a memory is used (not shown) to store the already encoded symbols while the remaining constellation symbols are generated. Alternatively, each constellation symbol is sent over the transmission channel as each symbol is encoded.

Figure 3 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) decoding system in accordance with the present invention. It should be noted that although the system in Figure 3 is described with respect to a trellis coding modulation scheme, the system in Figure 3 is useable in a pragmatic trellis coding modulation scheme as well. The TCM decoding system 300 shown in Figure 3 includes a soft decision metric generator (SDMG) 302, a turbo product code (TPC) decoder 304, a turbo product code (TPC) encoder 306, an uncoded bit decision generator (UBDG) 308 and an output multiplexer 310. The SDMG 302 is coupled with the UBDG 308 and the TPC decoder 304. The UBDG 308 is coupled with the SDMG 302, the TPC encoder 306 and the output multiplexer 310. The TPC decoder 304 is coupled with the SDMG 302, the TPC encoder 306 and the output multiplexer 310. The TPC encoder 306 is coupled with the UBDG 308 as well as the TPC decoder 304. It should be noted that although the above modules are only shown and described in Figure 3, other modules may be added or substituted to the decoding system 300 in accordance with the present invention. In addition, the present system may be used in other sized constellations such as QPSK or any sized quadrature amplitude modulation schemes.

Figure 4 illustrates a constellation map for an 8PSK modulation scheme. In particular, the constellation map has an I-axis (in-phase) and a Q-axis (quadrature), whereby constellation symbols or points are positioned on the map based on their (I,Q) coordinates. For a particular modulation scheme, there are 2^m points in the mapping constellation, where m is the number of bits per constellation point or symbol. For example, in an 8PSK modulation scheme, m is equal to 3 pre-mapped symbols per constellation symbol, the pre-mapped symbols being U_1, C_1, and C_2. In other words, for an 8PSK modulation scheme, pre-mapped symbols U_1, C_1, and C_2 are utilized to map a particular constellation symbol (I,Q). As shown in Figure 4, 8 constellation points are displayed at different locations, wherein each constellation point has a different set of I and Q coordinates. In addition, as shown in Figure 4, each quadrant in the constellation includes 2 constellation points. As discussed above, each constellation point is positioned with respect to the bit values of symbols U_1, C_1, and C_2. For example, the first quadrant in Figure 4 includes points 1 and 2, whereby point 1 comprises bits $U_i=0$, $C_i=0$, and $C_2=0$ and point 2 comprises bits

$U_1=0$, $C_1=0$, and $C_2=1$ and so on. Based on the type of modulation scheme, each
constellation point can be grouped into a particular set based on the location of each
constellation point having the farthest distance to every other constellation point in the
map. For example, in Figure 4, points 1, 3, 5 and 7 are a distance furthest from each
other, whereas points 2, 4, 6 and 8 are a distance farthest from each other. Thus,

5   points 1, 3, 5 and 7 are designated as a first set and points 2, 4, 6 and 8 are designated
a second set. Therefore, for an 8 PSK modulation scheme, the constellation map is
partitioned into 2 QPSK schemes having 4, instead of 8, constellation points in a set.
It should be noted that the above discussion applies to other sized constellations such
as QPSK or any sized quadrature amplitude modulation schemes.

10   This designation of sets simplifies the demapping process for the decoding
system 300. As the data 220 is transmitted over the transmission channel, the
presence of Additive White Gaussian Noise (AWGN) in the channel deteriorates the
integrity of the data 220. Thus, a constellation symbol having coordinates (1,1) may
have coordinates of (2.1,0.5) when received at the receiving end. To aid the decoding

15   system 300 in determining the bit values based on the new (I,Q) values, the decoding
system 300 can use information provided to it as to which set the (I,Q) constellation
symbol belongs to. In other words, if the decoding system 300 knows that the
received (I,Q) symbol belongs to the first set of symbols, the decoding system 300 can
look only to the 4 constellation points in that first set, rather than looking at all 8

20   constellation points, to determine the values of U_1, C_1, and C_2.
            Referring back to Figure 3, the SDMG 308 of the present invention preferably
receives the (I,Q) symbol after the symbol has been transmitted over the transmission
channel. The integrity of the (I,Q) symbol changes as it is transmitted due to noise in
the transmission channel, such as Additive White Gaussian Noise (AWGN). Thus,

25   SDMG 308 preferably produces the soft decision metric values or metrics for each bit
transmitted over channel using log likelihood ratio (LLR) techniques, which are
known in the art. Alternatively, the SDMG 308 produces the soft decision metrics
using PSK or QAM soft decision value look up tables, which are known in the art.
Using this method, the SDMG 308 uses Euclidean distances as well as automatic gain

30   control actions to normalize the amplitude of the received point to unity. For higher
mapping orders, such as QAM symbols, the SDMG 308 can use any other available
techniques, such as Gray mapping scenarios, etc.
            Regarding the UBDG (uncoded bit decision generator) 308, the UBDG 308
generally receives the n reencoded bits provided by the TPC encoder 306 (see below)

35   as well as the (I,Q) symbols received over the transmission channel. The UBDG 308
then uses this information to determine the value of the uncoded u bit. It is preferred
that the UBDG 308 determines the uncoded u bit by the use of special look-up tables.
Alternatively, the UBDG 308 utilizes logic, modulation or ROM to determine the
value of the uncoded u bit which was supplied to the pre-mapping module 206 (Figure

2) from the demultiplexer 202 (Figure 2).

In operation, the constellation symbols (I,Q) for the given codeword are received by the decoding system 300 after the constellation symbols have been transmitted over the transmission channel. Since the constellation symbols most likely will have different I and Q values due to noise present in the channel, the

5   SDMG 302 generates n soft decision metrics of the coded data using any of the methods described above. It is preferred that all of the sent constellation symbols are received by the SDMG 302 before the SDMG 302 processes the symbols or outputs any soft decision metrics. Thus, a memory is used (not shown) to store the constellation symbols as the remaining constellation symbols are still being received

10   in the SDMG 302. Alternatively, the SDMG 302 processes or outputs the soft decision metrics as the constellation symbols are received at the SDMG 302. The SDMG 302 sends these n soft decision metrics 316 to the TPC decoder 304, wherein the TPC decoder 304 decodes the n soft decision metrics into k decoded bits 318. Preferably, the TPC decoder 304 utilizes a turbo product code decoding scheme are

15   described in U.S. Patent Application Serial Number 09/406,252, filed September 27, 1999, and entitled "Turbo Product Code Decoder", the content of which are hereby incorporated by reference. Alternatively, the TPC decoder 304 utilizes any other available turbo product code decoding scheme.

The k decoded bits are directly provided by the TPC decoder 304 to the output

20   multiplexer 310, whereby the output multiplexer 310 preferably waits to receive the decoded u bits from the UBDG 308. In this case, the output multiplexer 310 is coupled with a memory (not shown) to store the received k decoded bits. Alternatively, the output multiplexer 310 outputs the k decoded bits as they are received from the TPC decoder 304 and subsequently outputs the u bits once they are

25   received from the UBDG 308.

The TPC decoder also provides the k decoded bits to the TPC encoder 306. It is preferred that the TPC encoder 306 encodes the decoded k bits 318 with a forward error correction scheme. The forward error scheme preferably includes extended hamming codes and parity codes. However, any other known turbo product code

30   encoding scheme may also be used. In addition, the TPC encoder 306 may be any known or available encoder. The TPC encoder 306 reencodes the k decoded bits 318 to generate n reencoded bits 322, whereby the TPC encoder 306 sends the n reencoded bits 322 to the UBDG 308. The TPC encoder 306 reencodes the k bits that are already decoded to ensure that the UBDG 308 receives the most reliable data. Since the TPC

35   encoder 306 incorporates a forward error correction scheme to encode the k decoded bits, the UBDG 308 can use the extra error correction bits as well as other information provided by the TPC encoder 306 to accurately determine the value of the u bits for a given codeword. In addition, as stated above, the SDMG 302 provides the UBDG 308 with the (I,Q) symbols 314 as they are received over the transmission channel. It

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is preferred that the SDMG 302 supplies the (I,Q) symbols 314 to the UBDG 308 as the TPC encoder 306 provides the UBDG 308 with the n reencoded bits 322. Alternately, the UBDG 308 is provided with the (I,Q) symbols 314 and the n reencoded bits 322 at different times, whereby the UBDG 308 utilizes a memory (not shown) to store the information already received. Once the (I,Q) symbols 314 and the
5   n reencoded bits 322 are received, the UBDG 308 uses the above described method to estimate or determine the values of the uncoded u bits 324. Upon determining the value of the uncoded u bits for the given codeword, the UBDG 308 forwards the uncoded u bits to the output multiplexer 310. The output multiplexer 310 thereby outputs the uncoded u bits as well as the decoded k bits as decoded data 326. It is
10   preferred that the output multiplexer 310 receives all uncoded u bits as well as all k bits for the given codeword before the data is output. Thus, a memory (not shown) is used to store the already received bits as the remaining bits are being received. Alternatively, the output multiplexer 310 outputs each bit, uncoded or coded, as each bit is received by the output multiplexer 310.
15   Figure 5 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) encoding system 500 in accordance with the present invention for encoding a $(32,26)^2$ turbo product code. It should be noted that although the system in Figure 5 is described with respect to a trellis coding modulation scheme, the system in Figure 5 is useable in a pragmatic trellis coding modulation scheme as
20   well. As shown in Figure 5, the encoding system 500 includes a demultiplexing module 502, a turbo product code (TPC) encoder 504, a pre-mapping module 506 and a mapping module 508. The demultiplexing module 502 is coupled with the TPC encoder 504 and the pre-mapping module 506. The TPC encoder 504 is coupled with the pre-mapping module 506. The pre-mapping module is coupled with the mapping
25   module 508.
      Generally, as shown in Figure 5, the demultiplexing module 502 receives the input data 510 and splits the data 510 into two or more data streams. The turbo product code encoder 504 utilizes error correction schemes known in the art to the data that is to be encoded 513. The pre-mapping module 506 preferably interleaves
30   more than one data stream in such a way as to alleviate the problem of confidence levels being different for each of the bits in a given higher order modulation symbol. The bit mapping module 508 takes the coded symbols provided by the pre-mapping module 506 and maps them to the (I,Q) points of the constellation diagram. In this example, the constellation diagram is an 8PSK modulation scheme, as shown in
35   Figure 3. However, the present system may also be used in other sized constellations such as QPSK or any sized quadrature amplitude modulation schemes. It should be noted that although the above modules are only shown and described in Figure 5, other modules may be added or substituted to the encoding system 500 in accordance with the present invention.

As shown in Figure 5, input data 510 for a given codeword having a block size of 676 bits preferably enters the system 500 in a serial fashion and is de-multiplexed by the demultiplexing module 502. The demultiplexing module 502 demultiplexes the input data 510 into two streams, namely the non-encoded stream 516 and the to-be encoded stream 513. The non-encoded stream 516 that is sent directly from the

5   demultiplexer 502 to the pre-mapping module 506 contains 512 uncoded u bits, as shown in Figure 5. As stated above, it is preferred that each constellation symbol includes one uncoded symbol U_1 and two coded symbols C_1 and C_2. It is also preferred that the number of uncoded u bits is equal to one-half of the total number of n bits that are encoded by the TPC encoder 306 in an 8 PSK scheme. As will be

10   described, the TPC encoder 306 in the present example is set to encode a $(32,26)^2$ turbo product code block for a given codeword, wherein the number of k information bits is 676 bits. Therefore, the TPC encoder 306 will generate a total number of 1024 encoded bits for the given codeword. Thus, the number of uncoded u bits will be equal to 512 bits for the given codeword. Considering this, the demultiplexer 502

15   sends the 676 information bits of the block to the turbo product code encoder 504 via the to-be encoded stream 513.

The TPC encoder 504 receives the 676 information bits from the demulitplexer 502 and encodes the 676 bits with the appropriate forward error correction scheme. Thus, as stated above, the TPC encoder generates a $(32,26)^2$

20   encoded block having a total of 1024 encoded bits. It should be understood that the present TCM encoding system 500 is not limited to any particular turbo product code or turbo product code encoding scheme.

Once the 676 information bits have been encoded by the turbo product code encoder 504, the encoder 504 sends the encoded 1024 bits 514 to the pre-mapping

25   module 506. In the present example, the pre-mapping module 506 designates the 512 non encoded u bits into 512 pre-mapped U_1 uncoded symbols. In addition, the pre-mapping module 506 designates the two of the 1024 encoded bits into pre-mapped coded symbols C_1 and C_2. The pre-mapped U_1 symbol as well as the pre-mapped coded symbols C_1 and C_2 are then sent to the mapping module 508. Although this

30   example utilizes a ½ rate TPC encoder 504, the present invention is not limited to only one pre-mapped U uncoded symbol and two pre-mapped coded symbols C_1 and C_2 per constellation symbol. Thus, any number of pre-mapped coded and uncoded bits may be provided to the mapping module 508 by the pre-mapping module 506. The mapping module 508 then utilizes the symbols U_1, C_1 and C_2 to form 512

35   constellation symbols having (I,Q) coordinates. The constellation symbols (I,Q) are then transmitted over the transmission channel to the receiving end. It is preferred that all 512 constellation symbols are encoded for the given codeword before being sent over the transmission channel. Thus, a memory is used (not shown) to store the already encoded symbols while the remaining constellation symbols are generated.

Alternatively, each of the 512 constellation symbols is sent over the transmission channel as each constellation symbol is generated.

Figure 6 illustrates a block diagram of the preferred embodiment of the trellis coding modulation (TCM) decoding system in accordance with the present invention for decoding a $(32,26)^2$ turbo product code. It should be noted that although the system in Figure 6 is described with respect to a trellis coding modulation scheme, the system in Figure 6 is useable in a pragmatic trellis coding modulation scheme as well. The TCM decoding system 600 shown in Figure 6 includes a soft decision metric generator (SDMG) 602, a turbo product code (TPC) decoder 604, a turbo product code (TPC) encoder 606, an uncoded bit decision generator (UBDG) 608 and an output multiplexer 610. The SDMG 602 is coupled with the UBDG 608 and the TPC decoder 604. The UBDG 608 is coupled with the SDMG 602, the TPC encoder 606 and the output multiplexer 610. The TPC decoder 604 is coupled with the SDMG 602, the TPC encoder 606 and the output multiplexer 610. The TPC encoder 606 is coupled with the UBDG 608 as well as the TPC decoder 604. It should be noted that although the above modules are only shown and described in Figure 6, other modules may be added or substituted to the decoding system 600 in accordance with the present invention. In addition, the present system may also be used in other sized constellations such as QPSK or any sized quadrature amplitude modulation schemes.

The SDMG 608 receives each of the received 512 (I,Q) symbols and preferably produces a soft decision value for each of the coded bits in the symbol. The SDMG 608 preferably produces the soft decision values using log likelihood ratio techniques, which are known in the art. Alternatively, the SDMG 608 produces the soft decision values using PSK soft decision value look up tables, which are also known in the art. Using this method, the SDMG 608 alternatively uses Euclidean distances as well as automatic gain control actions to normalize the amplitude of the received point to unity. For higher mapping orders, such as QAM symbols, the SDMG 608 can use any other available techniques, such as Gray mapping scenarios, etc. Details of the SDMG 608 are discussed in detail above. Regarding the UBDG (uncoded bit decision generator) 608, the UBDG 608 takes the 512 (I,Q) constellation symbols that are received and, depending on the nature of the coded bits, unmaps the uncoded u bits 216 (Figure 2). The details regarding the UBDG 608 are discussed above.

In operation, as shown in Figure 6, the 512 (I,Q) constellation symbols are received by the decoding system 600, whereby the SDMG 602 generates 1024 soft decision metrics of the coded data using any of the methods described above. It is preferred that all of the sent constellation symbols are received by the SDMG 602 before the SDMG 602 processes the symbols or outputs any soft decision metrics. Thus, a memory is used (not shown) to store the constellation symbols as the remaining constellation symbols are still being received in the SDMG 602.

Alternatively, the SDMG 602 processes or outputs the soft decision metrics as the constellation symbols are received at the SDMG 602. The SDMG 602 sends these 1024 soft decision metrics 616 to the TPC decoder 604, wherein the TPC decoder 604 decodes the 1024 soft decision metrics back into the decoded 676 information bits 618. Preferably, the TPC decoder 604 utilizes a decoding scheme discussed above.

5   Alternatively, the TPC decoder 604 utilizes any other available decoding scheme.

The 676 decoded bits are directly provided by the TPC decoder 604 to the output multiplexer 610, whereby the output multiplexer 610 preferably waits to receive the uncoded u bits from the UBDG 608. In this case, the output multiplexer 610 is coupled with a memory (not shown) to store the received k decoded bits. The

10   TPC decoder 604 also provides the k decoded bits to the TPC encoder 606. It is preferred that the TPC encoder 606 reencodes the 676 bits that were decoded by the TPC decoder 604 with a forward error correction schemes, such as extending hamming codes, parity codes and/or any other known turbo product code encoding scheme. In addition, the TPC encoder 606 may be any known or available encoder.

15   The TPC encoder 606 reencodes the 676 information bits 618, such that the encoder 606 outputs 1024 reencoded bits 622 to the UBDG 608. The TPC encoder 606 reencodes the bits that have already been decoded by the TPC decoder 604 to ensure that the UBDG 608 is able to decode the pre-mapped U uncoded symbol with the most reliable data. Since the TPC encoder 606 incorporates a forward error correction

20   scheme to the 676 information bits in generating the 1024 reencoded bits, the UBDG 608 will be able to use the extra error correction bits to determine the value of the u bits for the given codeword.

As stated above, the SDMG 602 provides the UBDG 608 with the (I,Q) symbols 614 while the TPC encoder 606 provides the UBDG 608 with the 1024

25   reencoded bits 622. Upon determining the value of the 512 uncoded u bits for the codeword, the UBDG 608 forwards the value of the uncoded u bits to the output multiplexer 610. Once the output multiplexer 610 receives the determined values of the uncoded u bits from the UBDG 608, the output multiplexer 610 outputs the decoded data 626. The details of the output multiplexer 610 are well known in the art

30   and are not discussed herein. It is preferred that the output multiplexer 610 receives all uncoded u bits as well as all k bits for the given codeword before the data is output. Thus, a memory (not shown) is used to store the already received bits as the remaining bits are being received. Alternatively, the output multiplexer 610 outputs each bit, uncoded or coded, as each bit is received by the output multiplexer 610.

35   In an alternate embodiment of the present invention, the SDMG and UBDG are configured to work on a plurality of constellation symbols at one time. In addition, the SDMG and UBDG are configured to handle an unequal number of uncoded and coded bits in each symbol. For instance, using the above $(32,26)^2$ 2-dimensional TPC in a TCM scheme example, the overall block configuration of the

encoding system 500 and decoding system 600 will look the same. However, the system will process another amount of bits per plurality of symbols, instead of 2 coded bits per symbol. For example, the system would process 3 uncoded bits per two 8PSK symbols, thereby allowing the first 8PSK symbol to have 1 uncoded bit and 2 coded bits and the second 8PSK symbol having 2 uncoded bits and 1 coded bit.

5   Therefore, more than one symbol will be read into the bit mapping module 508 at a time. This would enable the entire system 500 to work in a complete block wise fashion.
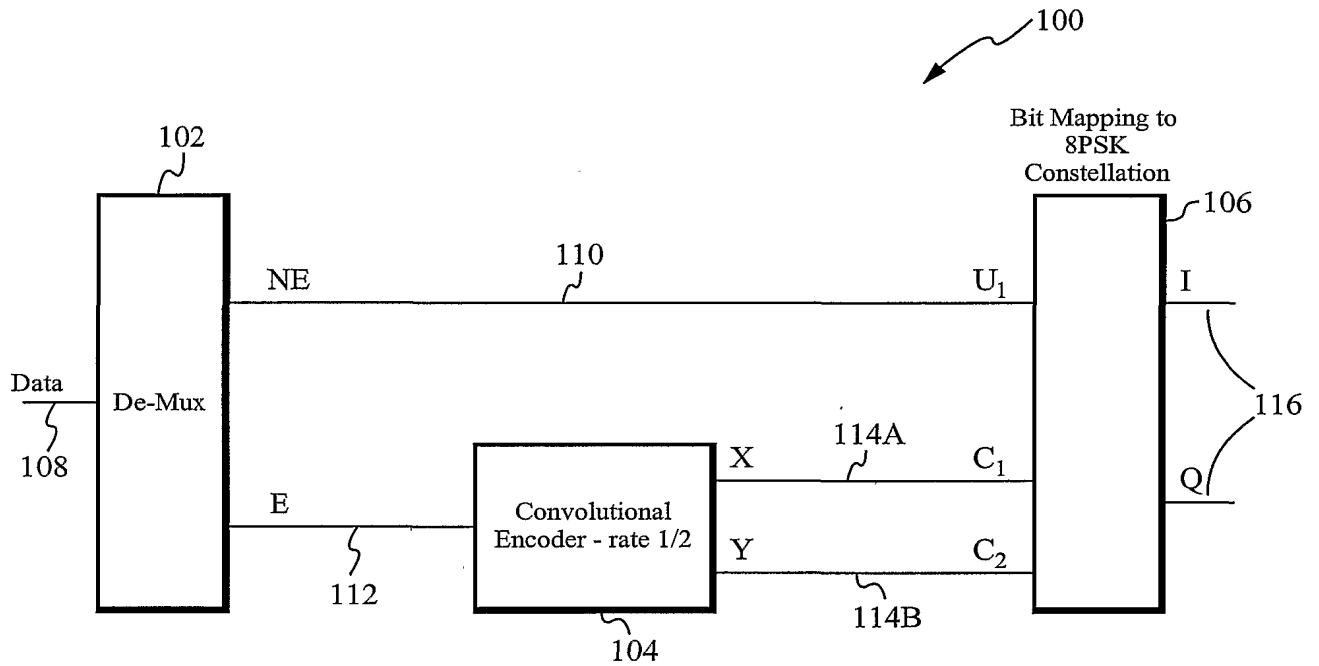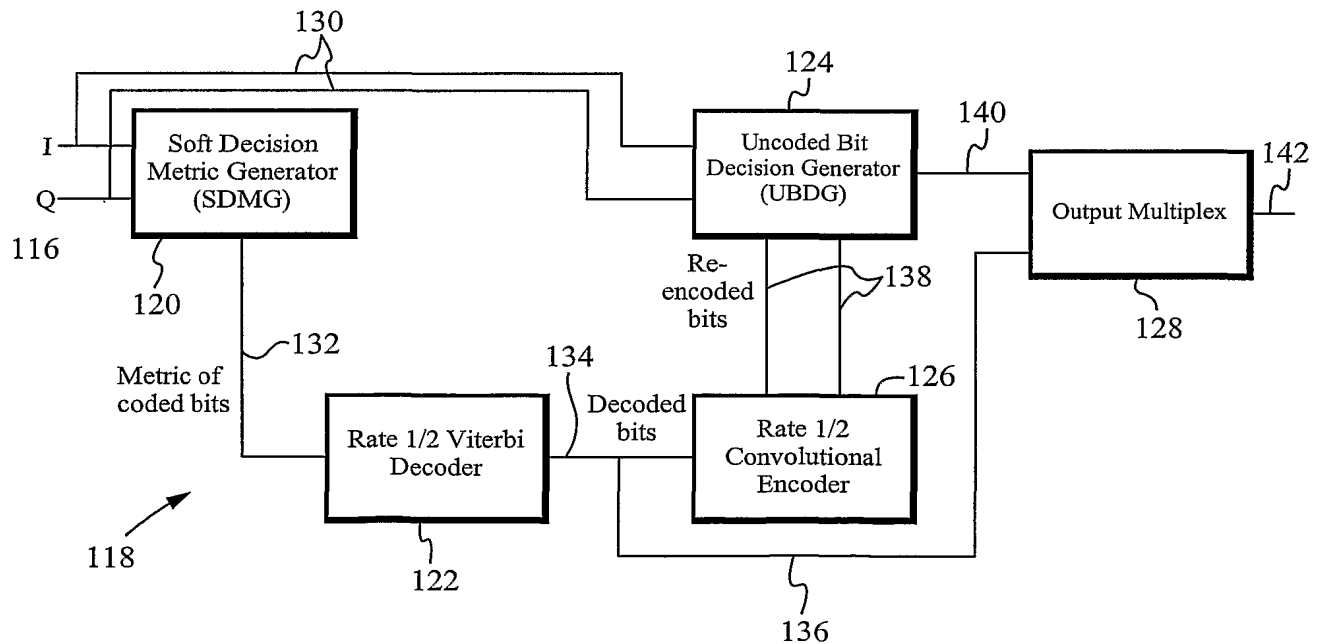
The present invention has been described in terms of specific embodiments incorporating details to facilitate the understanding of the principles of construction

10   and operation of the invention. Such reference herein to specific embodiments and details thereof is not intended to limit the scope of the claims appended hereto. It will be apparent to those skilled in the art that modification s may be made in the embodiment chosen for illustration without departing from the spirit and scope of the invention.

Claims

What is claimed is:

1   1.   A method of encoding a block of data for a given codeword comprising the

2   steps of:

3   a.   receiving the block of data, wherein the block of data is split into a first

4   stream of u bits and a second stream of k bits;

5   b.   encoding the second stream of k bits using a turbo product code

6   encoding scheme, thereby producing a stream of n encoded bits;

7   c.   generating a pre-mapped coded bit from at least one of the plurality of

8   n encoded bits;

9   d.   generating a pre-mapped uncoded bit from at least one of the u bits in

10   the first stream;

11   e.   mapping a constellation symbol having an I coordinate and a Q

12   coordinate, wherein the constellation symbol is calculated using the

13   pre-mapped coded bit and the pre-mapped uncoded bit.
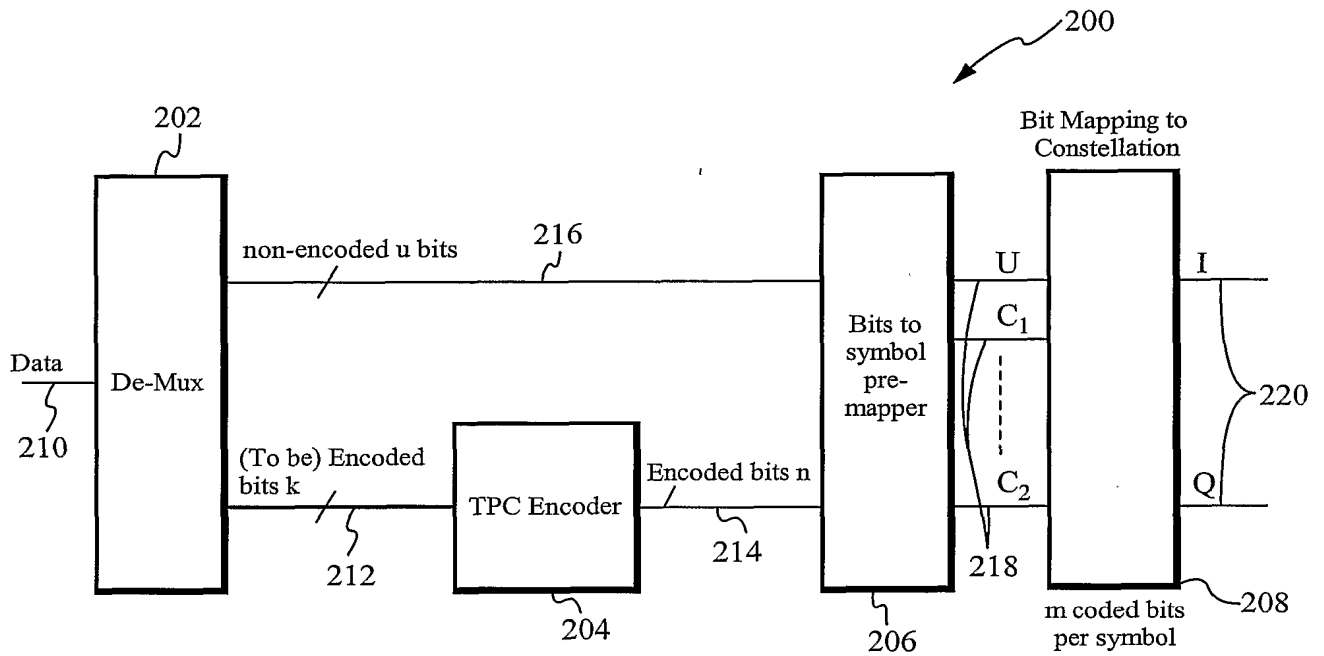
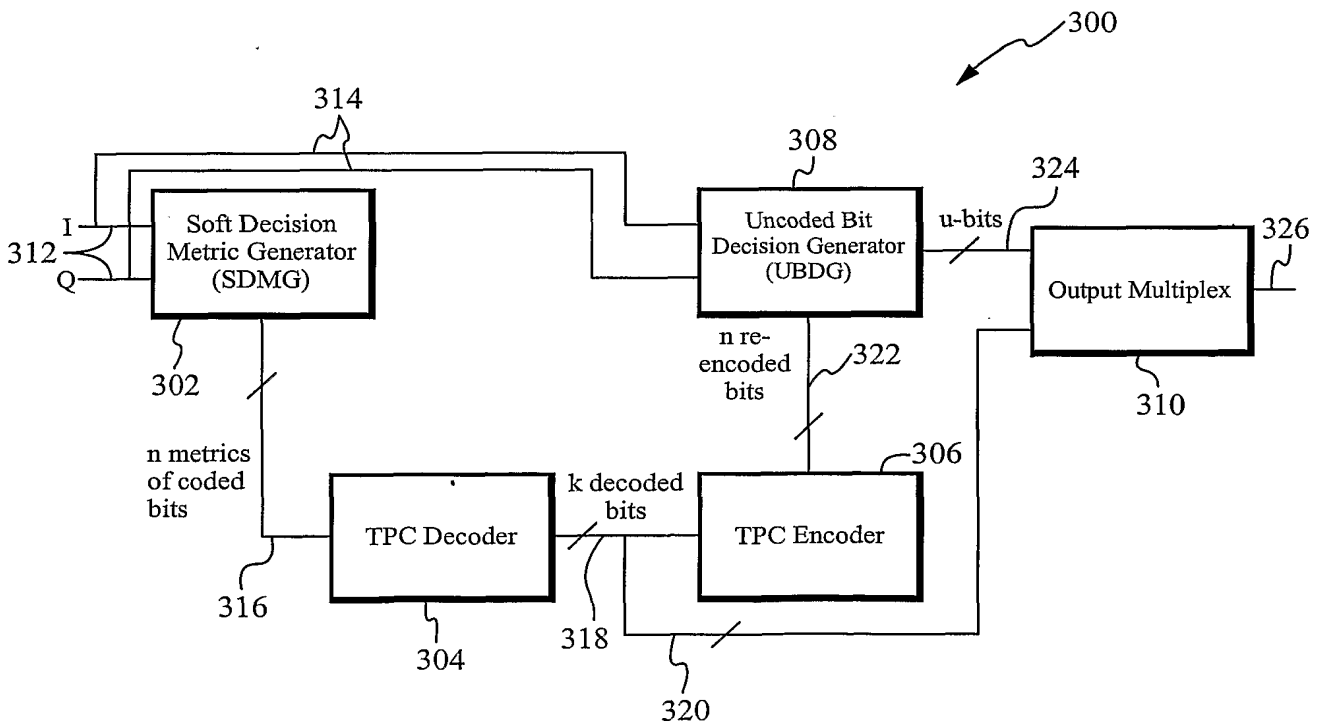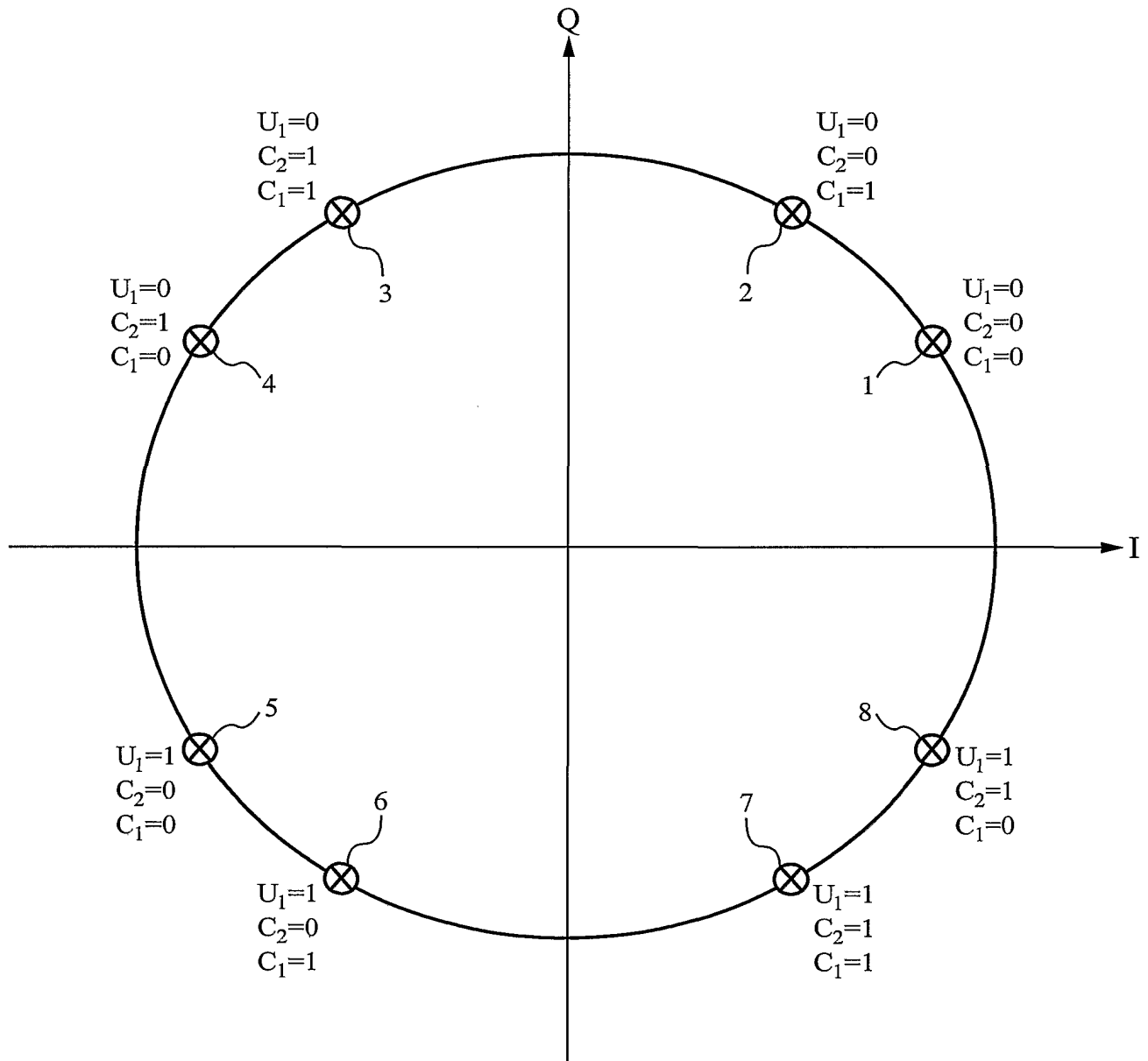Fig. 1A   (PRIOR ART)

Fig. 1B   (PRIOR ART)

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Fig. 2

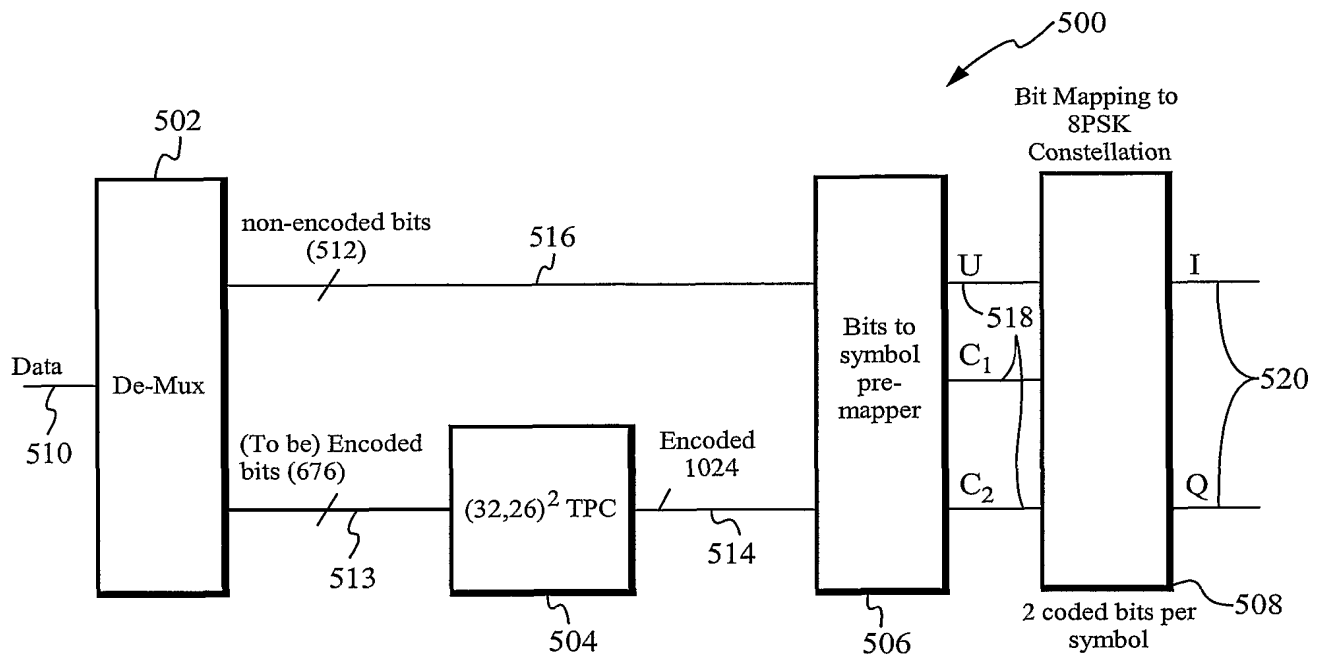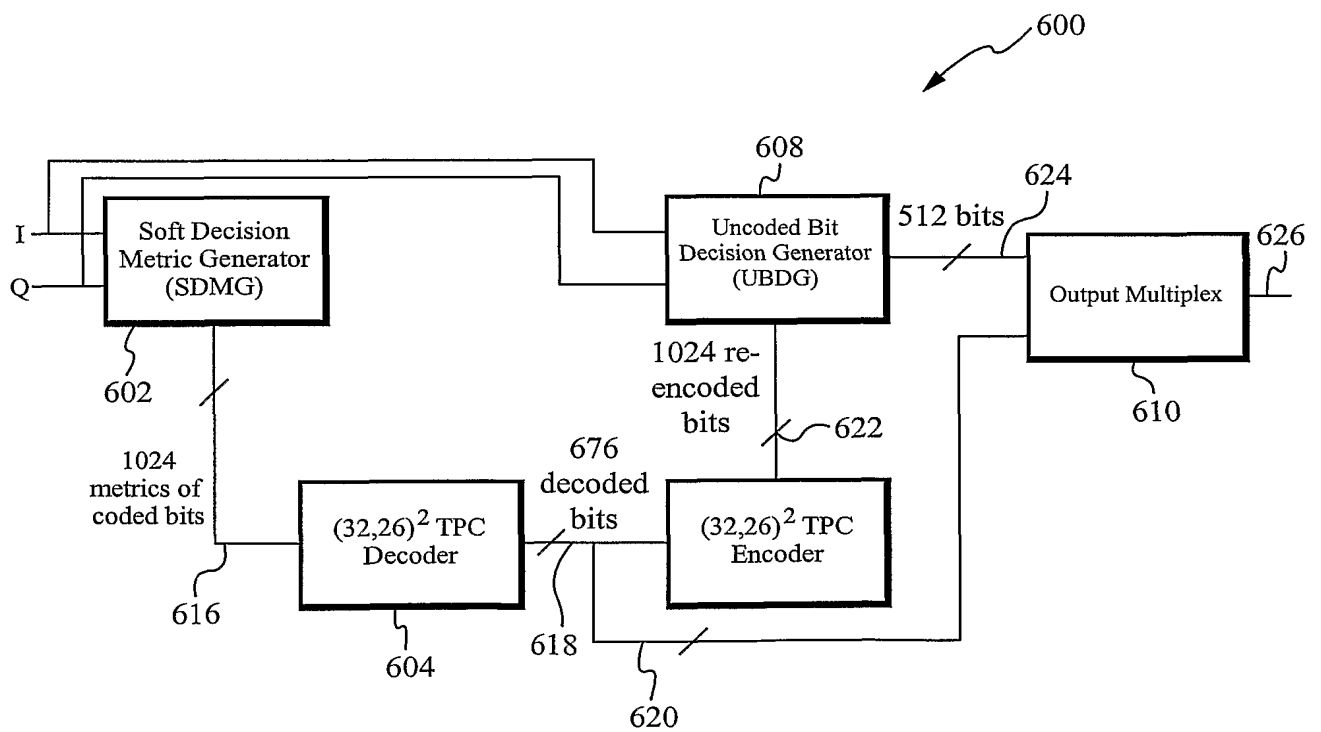
Fig. 3

Fig. 4

Fig. 5

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/21199

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H03M 13/29, 13/45; H04L 1/00
US CL : 714/755, 780; 375/260
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 714/755, 780; 375/260

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST, IEEE: "turbo product"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HEWITT, E., Turbo Product Codes for LMDS, 1999 Radio and Wireless Conference, August 1999, pages 107-111, especially the first paragraph of section II on page 107.	1
A	US 4.882,733 A (TANNER) 21 November 1989 (21.11.1989), figure 13.	1
A	US 5,416,801 A (CHOULY et al.) 16 May 1995 (16.05.1995), figure 3.	1
A	US 5,790,570 A (HEEGARD et al.) 04 August 1998 (04.08.1998), figure 1.	1
A	US 5,996,104 A (HERZBERG) 30 November 1999 (30.11.1999), figures 1 and 7.	1
A	US 6,000,054 A (BAHR et al.) 07 December 1999 (07.12.1999), figure 2.	1
A	US 6,034,996 A (HERZBERG) 07 March 2000 (07.03.2000), figures 2 and 3.	1
A, P	US 6,161,209 A (MOHER) 12 December 2000 (12.12.2000), columns 15-16.	1

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
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"&"	document member of the same patent family

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